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1.0 INTRODUCTION

The trend over the past decade, in the aeronautics and astronautics fields, is to provide increasing amounts of synthesized data for the human controller of a flight vehicle. One would expect this demand to continue on into the future. The major impetus for this trend is the continued distribution of computing capability to support integrated command and control of flight vehicles. This has given rise to the concept of an "operations management system". The definition of an operations management system, as used in this paper, is "that hardware and/or software which is responsible for the integrated operational control of aeronautic and astronautic distributed flight systems". This reflects the industry trend in avionics system engineering and integration (SE&I) toward operationally managing increasing amounts of data from an increasing number of sources, interpreting the data and using it in decision support systems for the operator. This is happening in the commercial and military aircraft business as well as in the manned and unmanned spacecraft business. When one peruses the literature one finds such titles as "vehicle management systems", "flight management systems", "cockpit management systems" and "mission management systems". They all have in common, the goal of providing an operational capability to manage this increasing volume of data without overwhelming the pilot, astronaut or automated control system.

2.0 OBJECTIVES

The overall objective of an operations management system is to provide an orderly and efficient method to operate and maintain aerospace vehicles. The purpose of the system is to aid in commanding and controlling the vehicle systems, whether distributed or centralized, in an integrated manner. This can be done in such a fashion that total vehicle status and response can be quickly understood and controlled. An operations management system must be built such that it and the other vehicle systems can evolve to support a flight program which may last for thirty years. For example, a particular automation technique may first be used under direct operator control, and later, as confidence is gained in the technique it would be allowed to function autonomously. Considerable production and operational efficiencies can be achieved by using modular and standardized software structures, common user controls, and standardized procedures shared by several vehicles. The achievement of commonality of design and control for all future aerospace vehicles requires continual emphasis in order to achieve significant reduction in our budgetary and human resources.

3.0 OMS PROVIDES THE FRAMEWORK FOR INTEGRATED COMMAND AND CONTROL

The fundamental philosophy behind the implementation of an operations management system is to perform as much processing as possible at the lowest architectural levels. This approach facili-

tates efficient use of a distributed information systems resources and provides the requisite flexibility to support operations as procedures change and when new system components are added or replaced. A Space Station Freedom (SSF) Operations Management System (OMS) is being designed which provides integrated command and control through a hierarchical architecture consisting of three levels or tiers. The tier structure can be thought of as being analogous to a classical business organization. Tier I is the high-level executive function. At this global level, general operating policies are enacted and enforced. For SSF, the flight crew, ground control centers, and OMS constitute Tier I.

Tier II is the line management, working largely autonomously to carry out utility systems and facility level functions and to fulfill the global requirements set at Tier I. Constituents of this architectural level include the distributed executives for systems such as Electrical Power, habitat and laboratory modules, and attached payloads. This level offers the possibility of accommodating future independent module operations, constrained only by the global oversight of Tier I.

Tier III is where subsystem and component operations and control occur. Denizens of Tier III include the so-called "smart" components, equipment racks, and payload groups. During operations, Tier III receives compact, concise instructions and commands are passed down from Tier I through Tier II. In the course of passing through each level, the command is successively "decomposed" into specific instructions directed to the appropriate target executives and components. Thus, the a terse Tier I instruction such as, "Perform a reboost in one hour" spawns hundreds of successor commands that propagate down through Tier III for ultimate execution.

These commands direct tasks such as targeting the burn, configuring the flight control system to support powered flight, configuring and verifying readiness of the propellant subsystems and securing payloads and experiments so that they can withstand the anticipated acceleration. In a corollary fashion, data from the lower architectural levels is synthesized as it negotiates its way to the top. Tier III components will typically be dealing with micro-instructions and data in terms of register contents and similar machine-specific constructs. In the case of a SSF reboost, Tier III might send a rather detailed accounting of their status to Tier II (but still less detailed than what exists at Tier III). What survives of this data when it reaches Tier I might be a simple "Go/No Go" statement of system readiness. This hierarchical approach to operations management, monitoring, command and control maximizes the efficiency of data processing and communications resources. The multi-tiered structure optimizes the interface at each level. Thus Tier I transactions are inherently amenable to the natural language constructs of the User Interface Language (UIL), while the machine-specific instructions at Tier III are best handled by the components at that level. Localizing the man-machine interface to a single architectural

level produces significant gains in human productivity while lowering training requirements and reducing exposure to procedural misunderstandings.

4.0 TECHNOLOGY ISSUES

Greater efficiency in the development and maintenance of aerospace vehicles utilizing operations management system approaches, requires meeting specific technological goals. These goals include advances in software development techniques and computer hardware capabilities.

Sound software engineering techniques need to be developed to allow production of code that is flexible, easy to share among diverse applications and inexpensive to build and maintain throughout its life cycle. An advanced software engineering development environment will increase the efficiency of code production, much like the use of spreadsheet programs increases the efficiency of financial and engineering calculations. Increased efficiency of code generation can be achieved through the use of expert systems-based tools that optimize software structures and aid the engineer in assembling applications from libraries of component software parts. Strong systems engineering, at the beginning of a program, can produce software products that are useful for a host of applications across other aerospace programs.

Standards for computer hardware need to be developed along with computers capable of interacting with other computers in an heterogeneous environment of hardware types and multiple software languages. Experience has shown that, despite the existence and use of standards, there is always a need for heterogeneity.

Experience with the use of expert systems and other advanced automation software techniques needs to be widened to the extent that enough engineering confidence is gained with them so that they will be utilized for command and control. Methods need to be developed to harness these techniques to achieve increasingly effective and efficient interactions between man and machine and interactions among machines. An increased emphasis is required on making these command and control interactions generic enough to be valid and useful across a variety of future aerospace vehicles and for upgrades to present vehicles.

5.0 RECENT DEVELOPMENTS IN OMS COMPONENTS

A conceptual architecture design activity for the integrated commanding of hierarchical distributed systems began at the NASA JSC in 1985 as a study for the Mission Operations Directorate (JSC 20792). This study provided the basis for the SSF onboard portion of the OMS. The final phases of this study coincided with the beginning of the OMS Working Group, which first met in early 1986 and provides the forum for discussions and dissemination of information related to design and implementation of the SSF OMS.

Standalone component prototypes were developed in Zeta Lisp on the Symbolics. A Procedures Interpreter (PI) component illustrated the use of different levels of automation in the execution and monitor of crew procedures. An Integrated Status Assessment (ISA) component performs failure analysis based on integrated models of the SSF utility systems. These components were first demonstrated in October 1986.

For other NASA programs several expert system based components have been developed and are in use to perform intelligent monitor and diagnosis of manned and unmanned systems operations. The Integrated Communications Officer (INCO) Expert System has been installed in the Mission Control at JSC, and is used by flight controllers during Naational Space Transportation System (NSTS) operations to perform automated monitoring of the communications equipment. The success of INCO has resulted in a number of similar projects that incorporate advanced automation in other flight control positions in Mission Control. Similarly, the Spacecraft Health Automated Reasoning Prototype (SHARP) is used at the Jet Propulsion Laboratory to perform automated health and status analysis. They are using SHARP for multi-mission spacecraft and ground data systems operations, with its initial focus being on the telecommunications link of the Voyager II spacecraft. Another application, that began as a proof-of-concept prototype and is finding use in operations, is the Maintenance Operations Management System (MOMS). MOMS uses advanced graphics and video techniques to assist in the execution of onboard maintenance procedures. MOMS is currently being installed in the Mission Support Room at JSC for use on the NSTS. Other expert system prototypes are also in development in the areas of flight plan generation and replanning and in fault diagnostics.

6.0 MAJOR ACCOMPLISHMENTS IN OVERALL SYSTEM DESIGNS

An operations management system represents the highest level of control in any hierarchical distributed environment. Space Station Freedom represents one such environment, although there are other examples, such as the command and control of deep space probes. Aspects of technology that are used in an operations management system include system health analysis, command and control, and plan generation and execution. An operations management system involves not only the real time aspect of operations, but also the support activities that make it possible to use advanced automation in real time control.

The SSF OMS Integration Group, at the Johnson Space Center (JSC) was formed in September 1987 to organize the effort to integrate prototype OMS software with other SSF system simulations. The OMS Integration efforts primary goal was to demonstrate an OMS integrated command and control architecture. This has been demonstrated in a phased manner, with the OMS prototype commanding a Guidance, Navigation and Control simulation with respect to global commands ("start the reboost"), while GN&C performs system specific functions("turn on jet 2"). The OMS prototype coordina-

tes appropriate global activities ("prepare all systems for reboost"). Phase Two, currently in test, saw the migration of the OMS prototypes from a Symbolics to a VAX computing environment, and the addition of more functions and simulations. Thermal Control, Communications and Tracking, Electrical Power have been added to the original reboost scenario along with a SUN hosted node representing the ground control segment of the OMS. Also added was a VAX-based Display and Control node representing the displays a crewperson would use when interacting with the OMS.

Future demonstrations have been planned that add more simulation nodes, especially for payloads, and add functions to the OMS node, extending both horizontal and vertical integration. This work has been planned through 1991. The additional OMS functions include the handling of the onboard short term plan, additional failure diagnosis, and contingency replanning functions. Other operational concepts involving an OMS are being studied such as the handing off of control between a onboard based OMS and a comparable ground based system.

The scope of the work addressed by the OMS Integration Group will expand beyond the single SSF manned base in efforts past the 1991 time frame. For example, the use of the OMS to coordinate SSF and NSTS joint operations will be investigated where Test Bed nodes represent involved systems and trajectory dynamics. Eventually, the effort will migrate to a computing environment that is more flight-like by using prototype onboard hardware at the representative nodes and executing flight type applications software.

7.0 SIGNIFICANT FUTURE MILESTONES

Figure 1 (Key Technologies For OMS Future Development), shows two technology areas, Expert Systems and Man-Machine Interfaces, which are key to the future development of an OMS. In addition, this figure identifies the new NASA programs which could benefit from these technologies. Advancement of the technology is divided into three areas of sponsorship; Research & Technology (R&T), Advanced Development and program level Design, Development, Test & Evaluation (DDT&E). The sponsor for each of these areas would carry the technology development through some level of completeness. These completeness levels, as defined by the Office of Aeronautics and Space Technology (OAST), are identified in the table below.

DDT&E	Level 7	Engineering Model in Space
Advanced Development	Level 6	Prototype/Engineering Model Tested
	Level 5	Component/Brassboard Tested in Relevant Environment
	Level 4	Critical Function/Characteristic Demonstration

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R&T	Level 3	Designs Tested Analytically or Experimentally
	Level 2	Conceptual Design Formulated
	Level 1	Basic Principles Understood

Each of the technologies in Figure 1 would be applied to fundamental operations management tasks (i.e., planning, diagnosis or system control) which are performed by the system to assist the human operators.The expert systems technology for control of complex dynamic subsystems will evolve from control of single sub-systems in the early Space Station era to hierarchical control of multiple sub-systems later, and to distributed control of many subsystems in the Mars Transfer Vehicles. As the expert system capabilities evolves, and as confidence increases, less human interaction and monitoring of the system will be required. This will free-up onboard crewperson time and reduce the number of ground support people. Man-Machine Interface (MMI) development must parallel the evolution of the expert system technology. Even though an automated capability may be controlling, the user must be provided with sufficient information to assess the state of the system and be allowed the option of manual override at any time without delay. The essence of the MMI is to permit the system to smoothly transition between operator control and automated control.

Expert Systems for monitoring and control of space hardware has been under development for several years at NASA centers. An important subset of this technology will be Fault Detection, Identification and Reconfiguration (FDIR) for flight hardware. The Ames Research Center (ARC) and the JSC, as part of the R&T base, have jointly developed a thermal control hardware expert system called TEXSYS. They are also formulating an electrical power Control expert system called PMACS. Later systems will combine individual subsystem controllers into multi-subsystem monitors which will allow coordinated control of an entire complex of space hardware. The Integrated Status Assessment (ISA) tool which is part of the SSF OMS integrated test bed at the JSC is an example of a global level expert system. Another major application of expert system technology is in the space mission planning and scheduling. In previous space programs, planning and scheduling was a manual task requiring a considerable staff of highly specialized people. Today, sophisticated software systems are being applied to the planning and scheduling tasks, but they are more of an aid to the planners rather than a substitute. Future systems will contain the added capability to recommend and suggest options and produce a conflict free mission plan containing a multitude of activities and constraint parameters. Work is underway at the GSFC and at the JSC, using the R&T base, to develop expert planning systems. The GSFC is currently performing proof-of-concept testing on a planning system called the Scheduling Concepts, Architecture and Networks (SCAN),for NASA operated free flyer space platforms.

Procedures and checklists have always played an important role in the operation of aeronautical and astronautic systems. For future systems, these procedures will still exist, but in a different form. For SSF and other new manned flight systems, the procedures will be in executable electronic form, permitting execution to be accomplished in a near manual step-by-step process, in a semi-automatic process where the computer and operator share in the execution of sequential steps, or fully automated where the operator gives permission for the computer to execute the procedure and the operator monitors. Prototypes of these procedure executors are being developed at the JSC for SSF as part of the SSF OMS integrated testbed activities under the SSF DDT&E. Systems currently in development use conventional keyboard and mouse devices for manual interaction. Future systems will use natural language interfaces and utilize higher level input devices such as voice recognition systems.

Development work underway within the NASA to produce advanced man-machine interfaces include the Operations and Science Instrument Support (OASIS) command and control system software created at the University of Colorado at Boulder Laboratory for Atmospheric and Space Physics (LASP). This system was originally created for remotely controlling the Solar Mesophere Explorer (SME) which was an earth-observing satellite that measured parameters related to ozone levels in the atmosphere. OASIS is now being used as the basic MMI structure for SSF OMS prototype development.

8.0 SUMMARY

This paper has described concepts for an operations management system and has highlighted the key technologies which will be required if we are to bring this capability to fruition. Without this automation and decision aiding capability, the growing complexity of avionics will result in an unmanageable workload for the operator, ultimately threatening mission success or survivability of the aircraft or space system. The key technologies include expert system application to operational tasks such as replanning, equipment diagnostics and checkout, global system management, and advanced man-machine interfaces. The economical development of operations management systems, which are largely software, will require advancements in other technological areas such as software engineering and computer hardware. Also, added emphasis on systems engineering and integration, early in the design phase, will result in systems which are flexible and expandable. Accomplishment of the above technological tasks consists primarily of emphasizing and strengthening existing efforts. Some basic research and development is ongoing in each of the areas identified. What is missing, is a focus and unified effort to apply these technologies to the operations management system problem.

9.0   KEY CONTACTS

The following personnel are currently involved with the development of operations management system capabilities.

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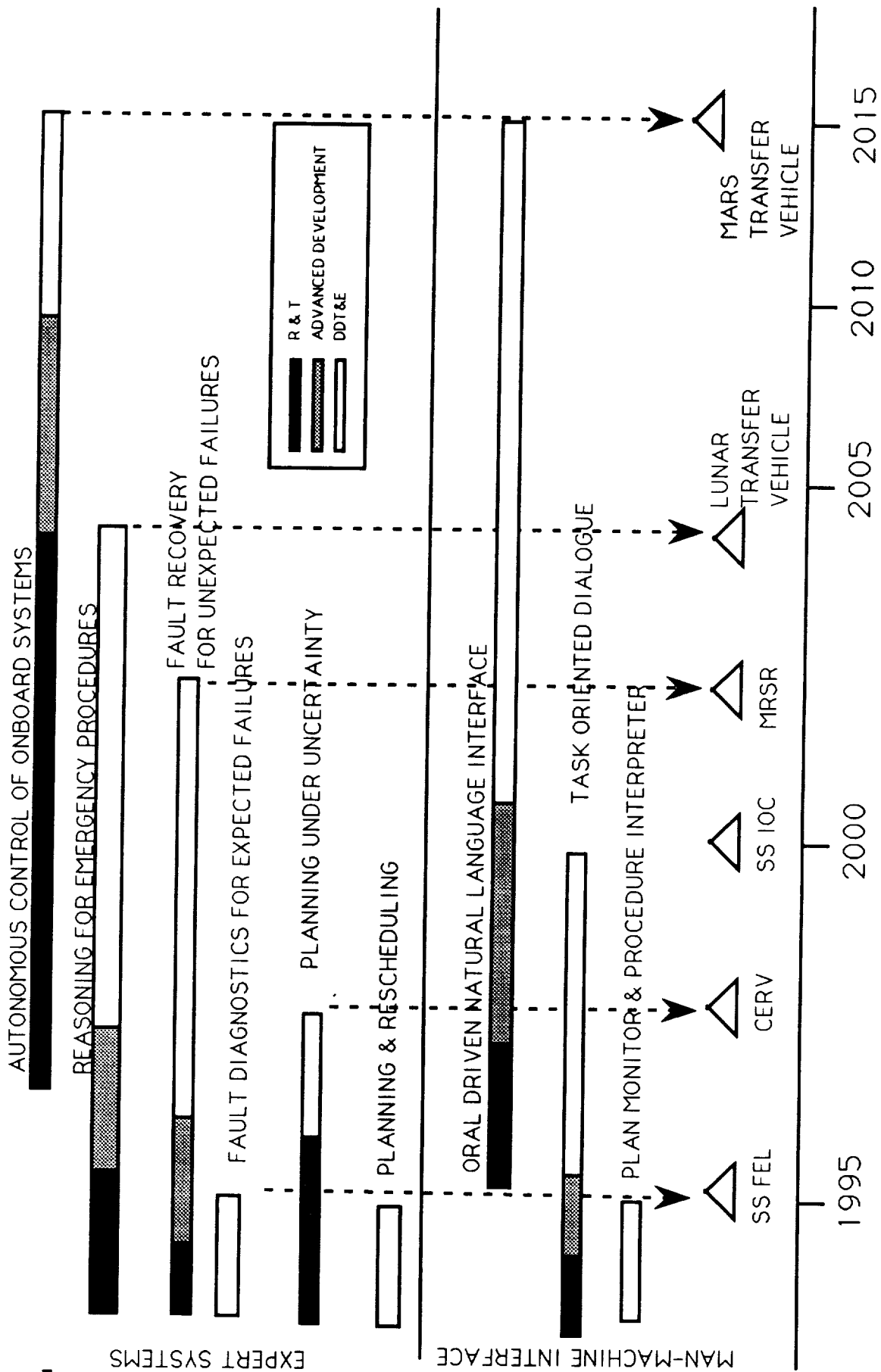K. Moe, NASA-GSFC
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FIGURE 1-KEY TECHNOLOGIES FOR OMS FUTURE DEVELOPMENT